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Spitzer 70-micron Confusion Level

D. T. Frayer and M. T. Huynh

220-6 Spitzer Science Center, Caltech, Pasadena, CA 91125

Abstract. *Spitzer* 70μm confusion measurements are presented based on ultra-deep MIPS-70μm observations of GOODS Hubble Deep Field North (HDF-N). The instrument noise for the MIPS-70μm band integrates down with nearly $t^{-0.5}$ for the low background HDF-N field. The estimated confusion level is $\sigma_c = 0.30 \pm 0.15$ mJy for a limiting flux density of 1.5 mJy ($q = 5$).

1. Introduction

The interpretations of the deep 24μm surveys (e.g., Yan et al. 2004; Le Floćh et al. 2005; Daddi et al. 2005; Papovich et al. 2006) are limited by possible strong emission and absorption features redshifted into the 24μm band and the expected wide range of the mid-infrared and far-infrared spectral energy distributions (SEDs) (e.g., Dale et al. 2005). Observations at 70μm are crucial for constraining the infrared luminosities and SFRs of the high-redshift *Spitzer*-selected galaxies.

The previous deep 70μm Multiband Imaging Photometer for *Spitzer* (MIPS, Rieke et al. 2004) Guaranteed Time Observer (GTO) surveys did not achieve sufficient sensitivity to detect individual sources which make up the majority of the Cosmic Infrared Background (CIB) and were unable to measure the confusion level at 70μm. The MIPS GTO deep surveys had integration times of only 10 minutes at 70μm and provided source counts to a shallow depth of 15 mJy (Dole et al. 2004a). In these proceedings, we report on the measured confusion level at 70μm based on ultra-deep (10.6 ks) observations of the GOODS Hubble Deep Field North (HDF-N).

2. Observations and Reduction

The MIPS 70μm observations of the GOODS HDF-N were carried in Cycle-1 of the General Observer program (*Spitzer* program 3325). The data were embargoed until after the MIPS GTO propriety period and were released to our team in 2005 August. The raw data were downloaded from the SSC archive (version S11) and were processed using the offline Germanium Reprocessing Tools (GeRT, S13 version 1.0), following the algorithms derived by the MIPS Instrument and Instrument Support Teams (Gordon et al. 2005). The instrumental artifacts in the basic calibrated data (BCD) products were removed adopting the filtering techniques used for the reduction of the extragalactic First Look Survey (xFLS, Frayer et al. 2006). The BCD pipeline processing and filtering procedures were optimized for these deep photometry data. We improved the sensitivity by 20% with respect to the on-line (version S11) filtered BCDs (fBCDs). We corrected the data for the updated calibration of MIPS (S13.2), assuming an absolute flux calibration factor of 702 MJy/sr per MIPS-70μm unit for stellar SEDs, and applied the appropriate color correction for galaxy SEDs. In comparison, the total calibration correction, including color corrections, is a factor of 1.20 times the pre-S13.2 versions of the on-line data products and is 3.4% larger than the calibration adopted for the xFLS analysis.

The data were combined with the *Spitzer* Science Center (SSC) mosaicking and source extraction software (MOPEX, version 112505) and were projected onto a sky grid with $4''$ pixels, correcting for array distortions. The average noise level of the image was derived empirically by making multiple aperture measurements at random locations throughout the residual mosaic after source extraction. The standard deviation of the random aperture measurements multiplied by the appropriate aperture correction was adopted for the average point source noise level.

3. Results

Previous surveys with *Spitzer* are not deep enough to measure the confusion level at 70μm. The published confusion estimates are based on predicted number counts from models of galaxy evolution (e.g., Dole et al. 2003, 2004b). With the ultra-deep data of HDF-N, we can directly measure the confusion level at 70μm. We define the instrument noise (including photon noise, detector noise, and noise associated with the data processing) as σ_I. The total noise (σ_T) represents the noise in the mosaic after the extraction of sources above a limiting flux density (S_{lim}), and the confusion noise (σ_c) represents fluctuations due to sources with flux densities below S_{lim}. As defined here, σ_c is the "photometric" confusion noise, following the terminology of Dole et al. (2003). In the direction of HDF-N, the contribution of Galactic cirrus to the confusion noise is negligible; the confusion noise is due to distant galaxies.

The instrument noise was estimated empirically by subtracting pairs of data with the same integration time and covering the exact same region on the sky to remove sources and any remaining residuals from the sky after filtering. The error bars for the instrument noise were derived by combining different independent pairs of data with the same integration time. We found a repeatability on the noise measurements of about 5% for long observations. The measured instrument noise integrates down nearly with $t^{-0.5}$ (Fig. 1). With the current processing and at the low background level of HDF-N, $\sigma_I^2 \propto t^{-1}(1 + \beta t^{0.5})$, where $\beta \simeq 0.04$ for integration time t in units of ks. The functional form of this relationship is based on empirical results from several different data sets taken over a range backgrounds and integration times. The β parameter was derived from a general weighted least-squares fit and depends on the background level and the quality of the data reduction. We used the above function to extrapolate the instrument noise from half the data to the entire data set and derived $\sigma_I = 0.0399 \pm 0.0036\,\mathrm{MJy/sr}$.

After source extraction, we measure σ_T. Since the total noise image and the instrument noise image have approximately Gaussian distributions, the confusion noise is also consistent with a Gaussian and is approximated by $\sigma_c =$

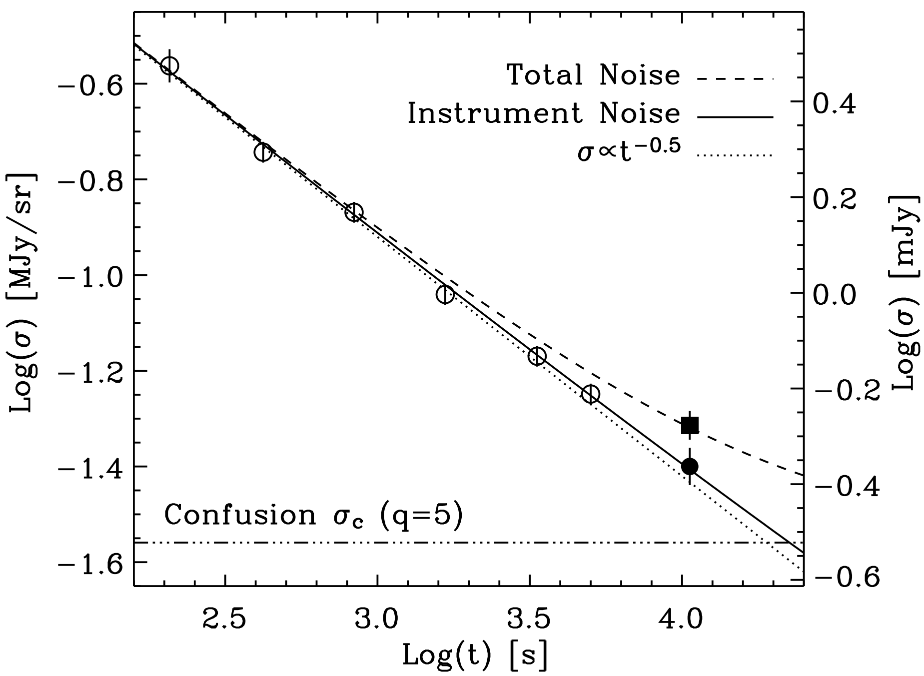

Figure 1. Measured rms noise for 4″ pixels as a function of integration time (1σ). The corresponding point source noise level in mJy is shown at the right. Instrument noise measurements are shown by the open circles and are represented by the solid line. For comparison, the dotted line shows a $t^{-0.5}$ function. The derived confusion level (σ_c) is shown by the dashed-dotted line, and the total noise after the extraction of sources with $S70 > 5\sigma_c$ is shown by the dashed line. The total noise and instrument noise for the HDF-N mosaic is shown by the solid square and solid circle respectively.

$(\sigma_T^2 - \sigma_I^2)^{0.5}$. We iterate between source extraction at different limiting flux densities and confusion measurements until we converge to a solution with $q \equiv S_{\rm lim}/\sigma_c = 5$. For the $q = 5$ solution, we derive $\sigma_T = 0.0485 \pm 0.0034$ MJy/sr and $\sigma_c = 0.0276 \pm 0.0079$ MJy/sr for a limiting source flux density of $S = 1.5$ mJy. Including the systematic uncertainties of the absolute calibration scale and the conversion between point source noise and surface brightness noise, we derive a point source confusion noise of $\sigma_c = 0.30 \pm 0.15$ mJy ($q = 5$).

In comparison, Dole et al. (2003) predict a $q = 5$ photometric confusion level of $\sigma_c = 0.224$ mJy and based on the updated predictions of Dole et al. (2004a), one would expect $\sigma_c \simeq 0.28$ mJy ($q = 5$), depending on the exact shape of the differential source counts. The measured confusion level of 0.3 mJy from the ultra-deep HDF-N data agree well with the predicted photometric confusion levels ($q = 5$). The 3.2 mJy confusion limit based on the source density criterion (SDC) adopted by Dole et al. is about a factor of two higher than the limiting flux density derived here. The Dole et al. SDC limit corresponds to $q \simeq 7$ and a high completeness level of $> 90\%$.

With these ultra-deep GOODS HDF-N data, we have derived faint source counts down to a flux density of 1.2 mJy, directly resolving the majority of the CIB due to galaxies at 70μm (D. Frayer et al. in preparation). Studies of the counterparts of the faint 70μm population are ongoing (M. Huynh et al., in preparation) and will help to constrain the infrared luminosities and the relative fraction of AGN versus starburst-dominated galaxies in the high-redshift *Spitzer*-selected surveys.

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